Agricultural innovation—necessity is the mother of invention

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Abstract

Innovation is the process leading to the adoption of new or existing information, technology or practices; it includes factors that affect demand for and use of knowledge in novel and useful ways. In agriculture, innovation is essential to maintain productivity growth, to address issues around sustaining the natural resource base and to adapt to climate change. This paper examines the innovation process in Australian agriculture, highlighting the shift from a ‘technology push’ to an approach that integrates factors that affect the demand or pull for knowledge, and the role of research and development in innovation.

Adoption of technologies is essentially a risk management problem: innovations that are profitable and exhibit a relative advantage will be readily adopted but will be influenced by other risk factors. Innovations are examined in the context of a return–risk framework. A case study on precision agriculture illustrates the innovation process and leads to a discussion on what future innovations are required. A survey of Nuffield scholars highlights some innovations that are being adopted and considered now. Most respondents have recently adopted innovations in soil management, crop management, plant breeding, precision agriculture and integrated pest and weed management.

In the coming decades, Australian agriculture faces many challenges that will require new farming systems that use land, water, nutrients, pesticides and energy more efficiently and better manage its risks. Farmers will need to continue to be adaptable, particularly given the changing environmental conditions, and innovation will be the key to maintaining productive and resilient farming systems.

Key words: technology, innovation, adoption, agriculture

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1 Why innovate?

Innovation is the process that can lead to the adoption of new or existing information, technology or practices; it includes factors that affect demand for and use of knowledge in novel and useful ways.

Innovations are essential to promote rural development, reduce poverty, stimulate or maintain economic growth, and adapt to scarce or variable resources. Demands to produce more from less are relentless and calls to feed a projected rising population are increasing, all while maintaining the natural resource base and responding to climate change (Tilman et al. 2002, FAO 2009). Research, development and extension are fundamental in the generation of innovations. Accordingly, the rural research and development (R&D) priorities include the ‘use of frontier technologies’ and ‘creating an innovative culture’. Of the total rural R&D expenditure, about 38 per cent is allocated to frontier technologies for building and transforming Australian industries’ (Mallawaarachchi et al. 2009).

2 Innovation process and Australian agriculture

The innovation process, or pipeline, covers a spectrum from idea to research through development and demonstration to adoption of new or existing information, technology or practices (Figure 1). Although the stages do not have distinct boundaries, and the processes and interactions between agents are more complex than shown in Figure 1, the pipeline concept is useful to focus analysis and discussion. The research component of the pipeline usually involves scientific experimentation. Development entails analysing and evaluating applied research results for their commercial viability, performance and value against existing or alternative devices or processes. It also includes the transfer and extension of research information with a view to maximising the benefit of the investment made. Demonstration involves the extension of potentially commercially viable products and processes and the dispersal of R&D data information and technology. In reality, there are iterative and interactive learning processes that occur between the innovation agents; and the process extends beyond the creation or push for knowledge to include the factors affecting the demand or pull for knowledge (Spielman and Birner 2008).

Historically, the emphasis was placed on technology invention and transfer through the optimisation of investment in public research and extension services (Spielman and Birner 2008). For example, Healy (1991) argued for Australian Government intervention in the development of enabling technologies because ‘they are fundamental to the growth of new agricultural industries and the revitalisation of older ones and are not tailored to specific markets’ (Healy 1991). Investment in Cooperative Research Centres followed and broadly address Healy’s enabling technologies although some have stronger linkages to agriculture than others.

Since 1991, the largely ‘technology push’ approach in Australia has been augmented with more emphasis on ‘demand pull’ in funding through the Rural Research and Development Corporations (RDCs) that have strong linkages to industry. RDCs may be either statutory or industry-owned, and include, for example, Meat & Livestock Australia, Grains Research and Development Corporation (GRDC), Fisheries RDC and Sugar RDC. The GRDC mission statement exemplifies this shift in emphasis: ‘To invest in innovation for the greatest benefit to its stakeholders. This will be achieved by being a global leader in linking science, technology and commercialisation with industry and community needs’ (GRDC annual report 2010). The Australian Research Council’s Centres of Excellence also have some industry affiliation. Recently, there has been the rise of a systems approach to innovation where all actors in the public and private sectors are involved in the creation, adaptation and use of agricultural knowledge.
3 Adoption in Australian agriculture

The process of adoption of new technologies is complicated and needs to be suited to the innovation and its customers (Barr and Cary 2000). Complex innovations will require more tangible efforts to be adopted and are likely to take longer than individual technologies. Established methods include:

- converting knowledge into readily transferable forms by using models to predict consequences in regions and seasons (Nix 1985) and by providing concise fact sheets, interviews and media articles
- having product champions who promote benefits, answer queries and support adoption
- overcoming barriers to change or adoption of an innovation by providing structures that are supportive and not restrictive
- demonstration of products as a preliminary stage in the process to full adoption
- participation of farmers or farm groups in R&D activities.

Factors in adoption of innovations

The decision processes that lead to adoption of innovations usually traverse through stages from awareness, through information seeking, through trialling, to reaffirming a decision for change. Adoption of technologies is essentially a risk management problem: innovations that are profitable and exhibit a relative advantage will be readily adopted, but will be influenced by other factors, including complexity, compatibility, environmental risk and the farmers' beliefs, motivations and attitudes to risk and change.

Keating et al. (2010) proposed an approach to explore returns to technological innovations relative to their riskiness. The return–risk framework suggests that efficiency frontiers exist at which the return from existing knowledge and innovation is maximised for different risk levels. Using this framework, Carberry et al. (2011) illustrated the key innovations adopted by Australian dryland crop producers over the past 30 years to improve farm performance and the key innovations that are likely to be adopted over the next 20 years. Technological innovations identified in this framework accord closely with results of a farmer survey (next section). The curves in figure 2 are styled examples of the
efficiency frontier framework: the lower, continuous line represents the frontier for the best technologies at a current point in time; the higher, dashed line represents the frontier for new innovations that create new return–risk dimensions. Using this framework, pathways for technology innovation can include:

- Moving from B to D by adopting current best practices to remove system inefficiencies with no increased exposure to risk.
- Moving along the efficiency frontier using existing technologies (D towards A) but with an associated increase in inputs and risk. Although not itself an innovation, it does result in increased outputs.
- Adopting breakthrough practices or technologies to move to a new efficiency frontier (dashed line) that enables either
  - maintained output through increased efficiency of resource use while reducing exposure to risk (D to C) or
  - increased output for the same level of risk (D to F).

Carberry et al. (2011) noted that, in reality, most farmers choose acceptable risk investments which return close to 60–80 per cent of the potential (point D) and that to increase returns with little added risk would require the adoption of breakthrough technologies (D to F). Comments captured in a survey of farmers (next section) confirm pragmatism in financial decision-making and include ways to manage risk such as involving new generation farmers in think tanks, and farm entities establishing a board to help with financial decisions.
Figure 2: Return–risk framework and innovations which either (a) affected Australian dryland agriculture from 1980 to 2010 or (b) are identified as having potential to affect Australian dryland agriculture between 2010 and 2030.

Note: A and D are representative points on the efficiency frontier for the best innovations at a point in time (—) and C and F are specific points on new efficiency frontiers for hypothesised new technologies (— -). Point B represents a position below the current efficiency frontier (Carberry et al. 2011). GM = genetically modified; G × E × M = genotype by environment by management interactions; ICT = information and communications technologies.

Farmers at the forefront: information and adoption
ABARES undertook a qualitative survey, targeting Nuffield Scholars as a group of agricultural producers at the forefront of innovation. The survey aimed to understand sources of information about innovations, and which innovations they have recently introduced to their farming businesses.
The 27 survey respondents were from a range of production types, including cropping, grazing, dairy and intensive production, across Australia. They were typically aged around 35–44, while the national average age of farmers in Australia is 54 (Australian Bureau of Statistics 2007-08).

Survey respondents were asked about the three most important resources they used for information about innovation. The most important resources were private agronomists or consultants and other farmers, followed by the internet, farm journals and industry-specific RDCs. Agricultural newspapers were less important sources of information. It is worth noting that none of the 27 respondents nominated ‘Other local and/or state government organisations (e.g. Rural Land Protection Boards, shire weed officers, government veterinary officers etc.)’ when asked to identify the three most important sources of information.

When asked about which journals and media they accessed, a majority of respondents listed both agricultural newspapers (either generally or specifically named newspapers) and the internet. The GRDC was also an important resource, being the industry RDC most closely related to many of the respondents. Nuffield Scholars were also enthusiastic attendees to field days and farm visits, as well as undertaking other activities that brought them into contact with innovations. Some respondents reported visiting farms or field days more than 50 times since January 2008, with 15 visits being the average during the period.

These results underline the importance of face-to-face contact with both experts and other users of innovations, seeing innovations demonstrated and having access to ‘champions’ in the form of consultants for the adoption of innovations (Barr and Cary 2000). Results also show the importance of information being readily accessible, either from consultants, the internet or other agricultural media, and demonstration of the economic returns from investing in innovation through other farmers and media.

Survey respondents were asked about what types of innovations they had adopted in the past three years. The range of responses reflects the variety of production systems respondents are involved in. The most adopted innovations were in soil management, crop management, plant breeding, precision agriculture and integrated pest and weed management. More than 20 respondents had adopted innovations of these types since January 2008.

About half the survey respondents had incorporated new machinery and automation innovations to their farm management in the survey period. These innovations typically require high capital investments. Farm incomes have been low in recent years, due mostly to persistent and widespread drought. ABARES (2011) reported that farm cash incomes for 2010–11 will be around 36 per cent higher than in 2009–10, and the highest since 2004–05. ABARES farm survey data indicate that levels of farm debt have increased markedly in the 2000s, with borrowing for funding new investment in land, machinery and vehicles and to develop land and farm improvements (ABARES 2011). Machinery and automation innovations accord the highest levels of consideration for adoption by survey respondents, perhaps reflecting the projected increases in farm incomes for the coming year.
The future according to farmers

Nuffield Scholars, when asked what they thought would be the most important innovations in the next decade, listed a broad variety of technologies. The most suggested innovations included improvements in stock and crops, for traits such as drought tolerance, chemical resistance and integrated pest management, and most respondents recognised genetic modification as an important tool in achieving these outcomes. Automation or mechanisation and innovations in soil management and health were also listed by many respondents.

When asked what innovations they want in the next decade, remote technologies and automation were common themes. Many farmers would like to be able to remotely control and automate repetitive tasks and monitoring functions, which could reduce labour costs and free up their time to manage their farms. Another common desire was the integration of multiple technologies and data. The explosion of technology and information gathering has led to an increase in information available to farmers, but this information needs to be better integrated. Both automation and integration can enable farmers to adopt better management practices on their farms, and to better manage variables to increase outputs and reduce inputs and wastes.

Many responses focused on innovations to underpin sustainable management of natural resources. Innovations to help them adapt to and mitigate climate change were also popular, with a large number wanting developments in the measurement and economics of soil carbon. There was also a high need for ‘non-production’ innovations, such as improved business management, increasing workforce capacity and ways to address the ageing of the farm workforce, marketing and value-adding to products. Increased investment in R&D was also flagged by a large number of respondents, recognising that the future would require having a choice of novel approaches to emerging issues.

4 Precision agriculture as a case study for an emerging technology and innovation

The survey of Nuffield Scholars demonstrated that precision agriculture is a widely adopted innovation, with almost all respondents having either recently taken up or considering incorporating a facet of precision agriculture into their farm management. Carberry et al. (2011) also identified precision agriculture as one of the innovations that may deliver productivity increase in Australian dryland agriculture. Precision agriculture allows customised and improved management of an agricultural system through the use of multiple information and sensing technologies (Cook and Bramley 2000). Precision agriculture improves control of a variable system, its risks, environmental impacts and, ultimately, profitability while/by improving managers’ skills. How this occurs will vary according to the problem and individual.

We can envisage three broad components to achieving precision agriculture (Robertson et al. 2006): sensing — measuring and collecting relevant data at desirable spatial scales; interpreting the data using a risk management framework to identify actions at spatial scales that are likely to deliver desirable outcomes; and delivering the actions on the ground with cost-effective technologies. Precision agriculture uses a number of component technologies, which approximately line up with those identified by Healy (1991) as shown in table 1. The processes, which are still developing and have mostly limited uptake thus far, are represented in the ‘funnel’ diagram in figure 3.
Table 1: Some major technologies contributing to precision agriculture and indications of their uptake in grain production (from Kearns and Umbers 2010). Potential links to enabling technologies identified by Healy (1991) are also provided.

<table>
<thead>
<tr>
<th>Component</th>
<th>Technologies</th>
<th>Uptake in 2008 by grain growers</th>
<th>Technologies identified by Healy (1991)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>% cropped area</td>
<td>% farms (range across regions sampled)</td>
</tr>
<tr>
<td>Sensing/data</td>
<td>Yield mapping</td>
<td>20.8</td>
<td>15.8 (0–26)</td>
</tr>
<tr>
<td></td>
<td>Remote sensing</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td></td>
<td>Electromagnetic soil survey</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td></td>
<td>Global Positioning Systems (GPS)</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Interpreting/deciding</td>
<td>Simulation models and Geographic Information System (GIS)</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td></td>
<td>Seasonal forecasts</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td></td>
<td>Zone selection</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Delivery/enacting</td>
<td>Machinery guidance</td>
<td>58.3</td>
<td>48.4 (25–69)</td>
</tr>
<tr>
<td></td>
<td>Controlled traffic</td>
<td>15.6</td>
<td>14.5 (1–39)</td>
</tr>
<tr>
<td></td>
<td>GPS</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td></td>
<td>Variable rate technology</td>
<td>12.4</td>
<td>13.0 (0–21)</td>
</tr>
</tbody>
</table>
Cook and Bramley (2000) were brave enough to suggest what might be achieved by 2010. They evoked a vision of production systems that maximised biological productivity by controlling inputs exactly to requirements of a given site and season. This has not yet been realised. A recent survey by GRDC (Kearns and Umbers 2010) into the adoption of certain production practices by grain growers indicated that for the 2008 winter growing season approximately 15 per cent of both area and farms were using controlled traffic technologies, although this was usually on larger farms.

Jochinke et al. (2006) considered that limited uptake of full precision agriculture in the Wimmera region was due to a combination of a small increase in profit, difficulties in applying to the small-scale variability in soils, and increased economic risk with higher production costs. Nevertheless, they observed that some component technologies such as tractor auto-steer were being adopted because of other benefits (reduced fuel and input costs, more timely operations). These tools seem to be getting cheaper with time and are more likely to be introduced onto farms with large-scale operations that enable the capital costs to be spread over a greater acreage or tonnage of product.

Other constraints to the adoption of precision agriculture commonly noted (Jochinke et al. 2006, Robertson et al. 2006, Mandel et al. 2010) include limited technical assistance, difficulties in data interpretation, compatibility issues between manufacturers (especially data transfer), access to GPS signals, and the difficulty observing its benefits. The amount of information generated by these tools risks making simple decisions overly complex, and information must also be processed into knowledge that can be applied if it is to be useful.

Although there is high awareness among farmers of the scale of yield limitations across paddocks (Mandel et al. 2010), the deep-seated management change of precision agriculture means that time and effort is needed to make precision agriculture fully functional. Many components, such as guidance systems and variable rate technologies, are adopted for their individual benefits before being incorporated into full precision agriculture. In the case of variable rate technologies, a pragmatic intermediate step is to
determine two or three zones with different yield potentials, which can be managed according to certain constraints uniformly within the zones (Whelan and McBratney 2003). The application of precision agriculture to livestock production is also proceeding apace (Trotter 2010). For instance, real-time tracking of livestock will help manage animal–livestock interactions (grazing pressure, health monitoring) with great potential to improve productivity and efficiency. Other technologies include walk-over-weigh systems to manage livestock weight gains and turn-off, better monitoring of pasture growth and soil properties.

Push and pull: the adoption of precision agriculture in southern Australia.

Mark Branson is the owner-manager of a 1200 hectare family farm in the lower north of South Australia, and a 2005 Nuffield Scholar. The farm grows nine varieties of annual crops and runs a self-replacing merino sheep flock. Mark is involved in new cropping technologies, using precision agriculture techniques across his property.

When yield monitors first became available in Australia around 1995, there was little research to convince growers like Mark of the economic benefits of investing in the innovation. Precision agriculture was in its infancy in Australia. The distributor of the technology, a fertiliser company, was able to show Mark maps of yield variation across his property, but was not able to demonstrate how investing in a yield monitor, or other precision agriculture innovations, would boost his profits.

In 2001, the Grains Research and Development Corporation (GRDC) invested in research to test the merits of the technology, and shortly after a group of growers (including Mark), agronomists and researchers in South Australia formed the Southern Precision Agricultural Association (SPAA). The Australian Centre for Precision Agriculture at Sydney University used SPAA and growers from other states to help deliver the GRDC research project.

In the early years, the SPAA held expos and meetings, supported research and produced publications, but adoption was slow and there was little demonstrated economic benefit from investment in precision agriculture.

In 2006, funding to the SPAA for a study on economic benefits of precision agriculture resulted in the publication of a book, aimed at landholders, which made the case for precision agriculture. In the following years, the SPAA received further funding from local, state and federal agencies to promote precision agriculture through grower groups, with the result that precision agriculture is now much more widely practiced.

The formation of a peak body with representatives from Australia and New Zealand (SPAA – Precision Ag Australia), through which grower groups coupled with ongoing support of agencies like the GRDC, has meant there is both a growing body of evidence of the benefits of precision agriculture and a body of expertise and knowledge for farmers to access. Mark Branson has been able to show significant gains from adopting precision agriculture innovations on his property. In 2006, research suggested annual gains in the order of $37 a hectare, but Mark estimates that the gain is now significantly higher.

Mark Branson pers comm

5 The future

In the coming decades, Australian agriculture faces a combination of complex challenges. These include changing water availability; a yield plateau for major crops; increasing costs for energy, nutrient and greenhouse gas emissions; disruption of farming systems as a result of climate change; and the need to balance production while sustaining natural resources and biodiversity assets. Meeting these challenges will require new farming systems that more efficiently use land, water, nutrients, pesticides and energy and are adaptable and resilient.
Farmers will need to be more adaptable than ever under changing conditions — all while still remaining profitable. As they move to increase the efficiency of their systems — both through reducing inputs such as energy and nutrients and reducing wastes including carbon — it will be critical to integrate information with technologies across production systems and indeed the entire food supply chain. For example, tracking the carbon emissions of particular product, such as a loaf of bread, will require sophisticated monitoring, reporting and integration of data across the supply chain. Integration of better controls, precision technologies and methods that address environmental effects and sustainability should lead to production advances and ensure that new management methods work together with environmental objectives (Day 2010). This is facilitated by the development of sophisticated and powerful computing and communications technologies, such as automated monitoring, wireless communications and global positioning systems.

Landscapes are likely to become more industrialised and intensified as these innovations in mechanisation and automation come on-stream. A major challenge lies in ensuring these future landscapes also sustain natural resources and environmental benefits. A key element of future development will be to meet increasing demands on land by intensification of low-carbon gas emitting agriculture, by all technological means possible (Harvey and Pilgrim 2010).

Innovation is more than just new technologies; it is also using new or existing ideas and information to solve problems in a novel way. Innovators might draw on sources often well outside their traditional scope, taking and applying ideas and information from non-farming sectors. Innovation will result from the pull in response to the needs of farmers and producers, rather than the push of technology developers.

Identifying the most promising investments and policy interventions has become more difficult as the objectives have shifted from increasing outputs and yields to transforming agriculture into a more responsive, dynamic and competitive sector (Spielman and Birner 2008). Day (2010) suggested significant innovations would arise in the following areas:

- increased efficiency in resource use for example, light conversion to biomass, carbon productivity per unit water consumption and net greenhouse gas benefit per unit production
- minimisation of non-productive losses
- increased control of complex systems
- better balance of production and sustainable natural systems.

Some of the technologies and innovations suggested by Day (2010) as being critical for farm system optimisation include:

- sensing and data acquisition
- hyperspectral imaging
- real time trace gas detection and identification of diseases
- biosensors
- information management, large complex data sources needing control
- spatial variability and optimised inputs
- real time machine control
- systems modelling
- data integration and mining
- models of farming systems, life cycle analysis optimisation and decision support
• holistic management systems (converting data to knowledge and practices).

Although the future is inherently unknowable, Australian farmers can expect to face intensifying risks such as changing climatic conditions, rising input costs, increasing pressures to manage resources sustainably and reduce greenhouse gas emissions, and the need to increase efficiency to ensure global food security. These necessities may be the mother of many inventions, such as the technologies and information currently available and continually funnelling through the pipeline. However, the degree to which agriculture can manage these and other risks effectively and profitably will depend upon the level of further investment in innovations across the board.
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